

**LENS MODULE FOR A THIN SCANNING DEVICE****CROSS-REFERENCE TO RELATED APPLICATION**

This application claims priority of Taiwanese application no. 092100458, filed on January 8, 2003.

**5 BACKGROUND OF THE INVENTION****1. Field of the Invention**

The invention relates to a lens module, more particularly to a lens module suitable for use in a thin scanning device.

**10 2. Description of the Related Art**

In recent years, scanning devices have been used quite widely. While functionality of scanning devices has increased, the trend is still to miniaturize the size thereof. The size of a scanning device depends on the size of a lens module, which serves to project an image of an original onto an image sensor, within the scanning device.

At present, a critical factor that determines the size of the lens module is the total length of an optical path and the back focal length. If the total length of the lens module or the back focal length is relatively long, the overall size of the lens module will definitely be larger. Attempts to reduce the total length so as to reduce the size of the scanning device necessitates the design of a lens module that can match the reduced total length in order to achieve a satisfactory imaging quality.

US Patent Nos. 5,386,312, 5,731,915, 6,014,262, 6,147,811 and 6,208,474 have disclosed lens modules of various types. However, due to limitations posed by optical design techniques and lens manufacturing techniques, the lens modules disclosed in the aforesaid patents are not able to meet the requirements for a reduced total length and a satisfactory imaging quality.

#### SUMMARY OF THE INVENTION

Therefore, the main object of the present invention is to provide a lens module for use in a thin scanning device.

Another object of the present invention is to provide a scanning device that incorporates the lens module of this invention.

According to a first aspect of the invention, there is provided a lens module for a thin scanning device. The lens module is to be disposed on an optical path from an original to an image sensor. The optical path includes a chief ray at zero-field propagating from a zero-field of the original to a zero-field of the image sensor. A chief ray at full-field propagates from a full-field of the original to a full-field of the image sensor. The lens module is to be disposed between the original and the image sensor such that the chief ray at zero-field and the chief ray at full-field form an angle greater than 30 degrees therebetween at a side between the lens module and the image sensor. The

optical path has a total length measured from the original to the image sensor. The lens module forms an object distance with the original. The total length is less than 1.5 times the object distance. An object  
5 height of the original when imaged on the image sensor is defined as an image height. The total length is less than five times the image height. The lens module comprises, in sequence from the original to the image sensor along the optical path:

10 a first lens having a focal length and a shape factor with identical signs, and disposed to form the object distance with the original;

a second lens having a focal length with a sign opposite to that of the focal length of the first lens,  
15 and a shape factor with a sign opposite to that of the shape factor of the first lens;

a stop having a center and disposed such that the chief ray at zero-field and the chief ray at full-field pass through the center of the stop;

20 a third lens with a positive focal length and a positive shape factor;

a fourth lens with a positive focal length and a negative shape factor; and

a fifth lens with a negative focal length and a  
25 positive shape factor;

one of the first, second, third, fourth, and fifth lenses having a largest diameter and two opposite

surfaces, the two opposite surfaces having curvature centers with identical signs;

a ratio of a diameter of the stop to that of the fifth lens being less than 0.5.

5 According to a second aspect of the invention, a scanning device comprises:

a transparent window adapted for placement of an original;

a light source proximate to the transparent window;

10 an image sensor disposed to form an optical path with the transparent window, the optical path including a chief ray at zero-field propagating from a zero-field of the original to a zero-field of the image sensor, a chief ray at full-field propagating from a full-field of the original to a full-field of the image sensor;  
15 and

a lens module disposed between the transparent window and the image sensor such that the chief ray at zero-field and the chief ray at full-field form an angle greater than 30 degrees therebetween at a side between the lens  
20 module and the image sensor.

The optical path has a total length measured from the original to the image sensor. The lens module forms an object distance with the original. The total length  
25 is less than 1.5 times the object distance. An object height of the original when imaged on the image sensor is defined as an image height. The total length is less

than five times the image height.

The lens module includes, in sequence from the transparent window to the image sensor along the optical path:

5        a first lens having a focal length and a shape factor with identical signs, and disposed to form the object distance with the original;

         a second lens having a focal length with a sign opposite to that of the focal length of the first lens,  
10        and a shape factor with a sign opposite to that of the shape factor of the first lens;

         a stop having a center and disposed such that the chief ray at zero-field and the chief ray at full-field pass through the center of the stop;

15        a third lens with a positive focal length and a positive shape factor;

         a fourth lens with a positive focal length and a negative shape factor; and

         a fifth lens with a negative focal length and a  
20        positive shape factor.

         One of the first, second, third, fourth, and fifth lenses has a largest diameter and two opposite surfaces, the two opposite surfaces having curvature centers with identical signs.

25        A ratio of a diameter of the stop to that of the fifth lens is less than 0.5.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Other features and advantages of the present invention will become apparent in the following detailed description of the preferred embodiments with reference to the accompanying drawings, of which:

5        Figure 1 is a fragmentary schematic view showing the internal construction of a thin scanning device incorporating the first preferred embodiment of a lens module according to this invention;

10        Figure 2 is a simplified schematic view of the first preferred embodiment of the lens module according to this invention;

      Figure 3 is a schematic view of the first preferred embodiment of the lens module according to this invention;

15        Figures 4A and 4B are ray fan plots of the first preferred embodiment;

      Figures 5A and 5B are spot diagrams of the first preferred embodiment;

20        Figure 6 illustrates distortion attributed to the first preferred embodiment;

      Figure 7 is a simplified schematic view of the second preferred embodiment of a lens module according to this invention;

25        Figure 8 is a schematic view of the second preferred embodiment of the lens module according to this invention;

      Figures 9A and 9B are ray fan plots of the second

preferred embodiment;

Figures 10A and 10B are spot diagrams of the second preferred embodiment; and

Figure 11 illustrates distortion attributed to the  
5 second preferred embodiment.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before the present invention is described in greater detail, it should be noted that like elements are denoted by the same reference numerals throughout the  
10 disclosure.

Figure 1 is a fragmentary schematic view showing the internal construction of a thin scanning device employing a lens module 3 according to the present invention. As shown, the thin scanning device includes  
15 a transparent window 7 adapted for placement of an original 5 thereon, a light source 1 proximate to the transparent window 7, a charge coupled device (CCD) image sensor 4 disposed to form an optical path 6 with the transparent window 7, and four reflecting mirrors 2  
20 disposed between the transparent window 7 and the image sensor 4 for forming the optical path 6. The first preferred embodiment of the lens module 3 is used in the scanning device, in which the transparent window 7 is a glass window of 3 mm in thickness, and the image  
25 sensor 4 has a chip (not shown), and a cover glass (not shown) disposed at a front end of the chip and having a thickness of 0.7 mm.

With further reference to Figure 2 (in which the transparent window 7 and the cover glass of the image sensor 4 are omitted for convenience of illustration) in combination with Figure 3, the first preferred embodiment of the lens module 3 according to this invention includes a first lens 31 proximate to the original 5, a second lens 32 disposed on one side of the first lens 31 which is distal from the original 5, a third lens 33 disposed on one side of the second lens 32 which is distal from the original 5, a fourth lens 34 disposed on one side of the third lens 33 which is distal from the original 5, a fifth lens 35 disposed on one side of the fourth lens 34 which is distal from the original 5, and a stop 36 with a center 37 and disposed between the second and third lenses 32, 33. It will be apparent hereinafter that the characteristics of the first, second, third, fourth and fifth lenses 31, 32, 33, 34, 35, and the stop 36 may vary depending on design requirements.

The optical path 6 includes a plurality of light rays 60 passing through the stop 36 and including a chief ray 62 at zero-field propagating from a zero-field (center) 51 of the original 5 to a zero-field (center) 41 of the image sensor 4. A chief ray 64 at full-field propagates from a full-field (edge) 52 of the original 5 to a full-field (edge) 42 of the image sensor 4. The optical path 6 has a total length (TT) measured from



the original 5 to the image sensor 4. The lens module 3 forms an object distance (P) with the original 5. An object height of the original 5 when imaged on the image sensor 4 is defined as an image height (IMA).

5        In use, when the light source 1 illuminates the original 5, light rays 60 reflected from the original 5 and carrying information of an image (not shown) on the original 5 pass through the transparent window 7 and propagate along the optical path 6 formed by the  
10       reflecting mirrors 2 and the lens module 3 for forming an image on the image sensor 4, which converts the image information into electrical signals in a known manner.

      The lens shape can be characterized by a shape factor. The greater the absolute value of the shape factor of  
15       a lens, the greater will be the curvature of the surface of the lens. To facilitate description, a surface of lens having a center of curvature relatively close to the image sensor 4 is defined herein as a positive radius, whereas a surface of lens having a center of curvature  
20       relatively close to the original 5 is defined herein as a negative radius. In addition, the first and second lenses 31, 32 that are interposed between the stop 36 and the original 5 are defined as a front lens group, whereas the third, fourth and fifth lenses 33, 34, 35  
25       that are interposed between the stop 36 and the image sensor 4 are defined as a rear lens group.

      By adjusting the parameters of the constituting

elements of the lens module 3 (such as the curvature center and diameter of each of the lenses 31, 32, 33, 34, 35, the size of the stop 36, the angle between the chief ray 64 at full-field and the chief ray 62 at zero-field, the image height (IMA), the correlation between the total length (TT) and the object distance (P), etc.), and with the aid of optical simulation software and with consideration given to the actual arrangement and the effects intended to be achieved, it is found that the lens module 3 of this invention should satisfy the following conditions:

(1) The lens module 3 is disposed between the transparent window 7 and the image sensor 4 such that the chief ray 62 at zero-field and the chief ray 64 at full-field form an angle ( $\theta$ ) greater than 30 degrees therebetween at a side between the lens module 3 and the image sensor 4;

(2) The total length (TT) is less than 1.5 times the object distance (P);

(3) The total length (TT) is less than five times the image height (IMA);

(4) The first lens 31 in the front lens group has a focal length and a shape factor with identical signs, and is disposed to form the object distance (P) with the original 5. The second lens 32 in the front lens group has a focal length with a sign opposite to that of the focal length of the first lens 31, and a shape

factor with a sign opposite to that of the shape factor of the first lens 31. The third, fourth and fifth lenses 33, 34 and 35 in the rear lens group have positive, positive and negative focal lengths, respectively, and  
5 have positive, negative, and positive shape factors, respectively.

(5) The stop 36 is disposed such that the chief ray 62 at zero-field and the chief ray 64 at full-field pass through the center 37 of the stop 36.

10 (6) One of the first, second, third, fourth and fifth lenses 31, 32, 33, 34, 35 has a largest diameter and two opposite surfaces, the two opposite surfaces having curvature centers with identical signs.

(7) A ratio of a diameter of the stop 36 to that of  
15 the fifth lens 35 is less than 0.5.

The first preferred embodiment of the lens module 3 as applied to a scanning device (such as a Toshiba 2950 CCD image sensor with 1200 DPI, 4  $\mu$ m, interlaced into 2,400 DP1, 21,432 pixels) will be described in  
20 detail hereinbelow. The parameters of the first preferred embodiment of the lens module 3 are set forth below in Table 1.

TABLE 1

Surface No.	R	D	N	$\nu$
a	7.937	1.21	1.84	42.7
5 b	13.950	0.29		
c	-698.309	0.7	1.76	26.5
d	10.577	0.26		
e	$\infty$ (stop)	0.1		
f	12.735	2.72	1.84	42.7
10 g	-23.227	0.29		
h	-11.244	5.19	1.84	28.6
i	-10.564	3.46		
j	-6.097	1.39	1.72	28.0
k	-12.943			

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wherein: R is the radius of curvature of each lens surface in units of mm; D is the distance (center thickness of each lens or the air gap between adjacent lenses) between neighboring lens surfaces and is in units of mm; N is the refractive index of each lens; and  $\nu$  is the Abbe number of each lens.

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In this embodiment, the object distance (P) from the original 5 to the first lens 31 is 155.15 mm. The total length (TT) is 190 mm. The focal lengths of the first, second, third, fourth and fifth lenses 31, 32, 33, 34, 25 35 are 21.95, -13.60, 9.80, 205.94, and -15.78,

respectively. The shape factors of the first, second, third, fourth and fifth lenses 31, 32, 33, 34, 35 are 3.64, -0.97, 0.29, -32.09, and 2.78, respectively. The fifth lens 35 has the largest diameter, 12.92 mm, and the curvature centers of both surfaces thereof are -6.08 and -12.94, respectively. The diameter of the stop 36 is 3.6 mm. The ratio of the diameter of the stop 36 (3.6 mm) to the diameter of the fifth lens 35 (12.92 mm) is 0.28, which is less than 0.5, thereby satisfying the aforesaid condition (7).

In addition, in this embodiment, the angle ( $\theta$ ) between the chief ray 64 at full-field that is proximate to the image sensor 4 and the chief ray 62 at zero-field is 39.53 degrees, which is greater than 30 degrees, thereby satisfying the aforesaid condition (1). The total length (TT) of 190 mm is less than 1.5 times the object distance (P) of 155.15 mm, which satisfies the aforesaid condition (2). Besides, the total length (TT) of 190 mm is less than five times the image height (IMA) of 40.8 mm, which satisfies the aforesaid condition (3).

Figures 4A and 4B are ray fan plots showing aberrations of the first preferred embodiment of the lens module 3 according to this invention. In these figures, the largest scale is  $20\mu\text{m}$ , and PX and PY respectively represent size of the stop 36 in the X-direction and the Y-direction. Figure 4A, in which

the image height (IMA) is 0 mm, illustrate spherical aberrations of the first preferred embodiment. Figure 4B, in which the image height (IMA) is 20.40 mm, illustrate off-axis aberrations of the first preferred embodiment. In these figures, EY represents sagittal aberration, while EX represents tangential aberration. As it can be noted that the off-axis aberration is below  $20\text{ }\mu\text{m}$ , the first preferred embodiment of the lens module 3 according to this invention is capable of providing a satisfactory image quality.

Figures 5A and 5B are spot diagrams of the first preferred embodiment of the lens module 3 according to this invention, illustrating respectively the sizes of the image points at the center and edge of the imaging surface of the image sensor 4. In this embodiment, the cell size of the image sensor 4 is  $4\text{ }\mu\text{m}$ , and the sizes of the image points of the lens module 3 at the center and the edge of the imaging surface of the image sensor 4 are  $2.9\text{ }\mu\text{m}$  and  $3.1\text{ }\mu\text{m}$ , respectively, which indicates that the imaging quality is quite satisfactory. Figure 6 illustrates distortion aberration attributed to the first preferred embodiment of the lens module 3 according to this invention. As shown, the distortion in this embodiment is less than 1%, which is quite satisfactory.

Figure 7 is a simplified schematic view of the second preferred embodiment of the lens module 3 according to

this invention. It is noted that the transparent window 7 and the cover glass of the image sensor 4 are also omitted therein for the sake of simplicity. In addition, the arrangement and definitions of the lens module 3 are the same as those in the first preferred embodiment.

With further reference to Figure 8, the second preferred embodiment of the lens module 3 likewise can satisfy the conditions (1) to (7) set forth hereinabove, and is incorporated in a scanning device, such as a Toshiba 2950 CCD image sensor (1,200 DPI,  $4\ \mu\text{m}$ , interlaced into 2,400 DPI, 21,432 pixels). Table 2 sets forth the parameters of the second preferred embodiment of the lens module 3 of this invention.

TABLE 2

Surface No.	R	D	N	$\nu$
a	18.160	5.05	1.74	27.2
b	11.558	16.70		
c	7.252	3.89	1.64	59.0
d	13.458	0.64		
e	$\infty$ (stop)	0.14		
f	24.409	3.37	1.71	54.0
g	-61.952	0.36		
h	-13.154	2.10	1.55	62.3
i	-7.015	0.81		
j	-4.689	3.96	1.85	23.8
k	-10.177			

wherein the definitions of  $R$ ,  $D$ ,  $N$ , and  $\nu$ , as well as the units of  $R$  and  $D$ , are the same as those in the first preferred embodiment.

5        In this embodiment, the distance from the original  
5 to the first lens 31 (object distance  $P$ ) is 130.58  
mm. The total length (TT) is 190 mm. The focal lengths  
of the first, second, third, fourth and fifth lenses  
31, 32, 33, 34, 35 are -42.43, 24.68, 24.56, 27.16,  
10       and -10.18, respectively. The shape factors of the first,  
second, third, fourth and fifth lenses 31, 32, 33, 34,  
35 are -4.50, 3.34, 0.43, -3.29, and 2.71, respectively.  
The first lens 31 has the largest diameter, and the  
curvature centers of both surfaces of the first lens  
15       31 are 18.160 and 11.558, respectively, both being  
positive. In addition, the diameter of the stop 36 is  
3.62 mm. The ratio of the diameter of the stop 36 to  
the diameter of the fifth lens 35 (12.46 mm) is 0.29,  
which is less than 0.5, thereby satisfying the aforesaid  
20       condition (7).

      In this embodiment, the angle ( $\theta$ ) between the chief  
ray 64 at full-field proximate to the image sensor 4  
and the chief ray 62 at zero-field is 35.55 degrees,  
which is greater than 30 degrees and therefore satisfies  
25       the aforesaid condition (1). In addition, the total  
length (TT) of 190 mm is less than 1.5 times the object



distance (P) of 130.58 mm, which satisfies the aforesaid condition (2). Besides, the total length (TT) is less than five times the image height (IMA), which satisfies the aforesaid condition (3).

5        Figures 9A and 9B are ray fan plots showing aberrations of the second preferred embodiment of the lens module 3 according to this invention. As shown, the off-axis aberration of the lens module 3 is below  $20\mu\text{m}$ . Hence, the second preferred embodiment likewise  
10        can achieve a satisfactory effect.

      Figures 10A and 10B are spot diagrams of the second preferred embodiment of the lens module 3 according to this invention, illustrating respectively the sizes of the image points at the center and edge of the imaging  
15        surface of the image sensor 4. In this embodiment, the cell size of the image sensor 4 is  $4\mu\text{m}$ , whereas the sizes of the image points of the lens module 3 at the center and edge of the imaging surface are  $3.2\mu\text{m}$  and  
       $4.0\mu\text{m}$ , respectively, indicating a good imaging quality.

20        Figure 11 shows distortion aberration attributed to the second preferred embodiment of the lens module 3 according to this invention. As illustrated, the distortion aberration in this embodiment is also less than 1%, indicating a satisfactory image quality.

25        In summary, a lens module suitable for use in a thin scanning device and capable of providing satisfactory

imaging results can be designed based on the aforesaid conditions, and optionally with the help of optical simulation software. Furthermore, a scanning device incorporating the lens module of this invention and  
5 designed according to the aforesaid conditions can have a reduced thickness

While the present invention has been described in connection with what is considered the most practical and preferred embodiments, it is understood that this  
10 invention is not limited to the disclosed embodiments but is intended to cover various arrangements included within the spirit and scope of the broadest interpretation so as to encompass all such modifications and equivalent arrangements.